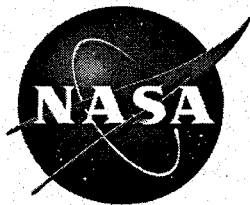


Balanced Flow Measurement and  
Conditioning Technology (Balanced  
Orifice Plate 7,051,765 B1)  
for  
NASA Inventions and Contributions  
Board Invention of the Year  
Evaluation



**Anthony R. Kelley**  
EV43 Advanced Sensors and  
Health Management Branch  
NASA Marshall Space Flight Center  
MSFC, AL 35812  
Phone: 256-544-7646  
Email: [anthony.r.kelley@nasa.gov](mailto:anthony.r.kelley@nasa.gov)

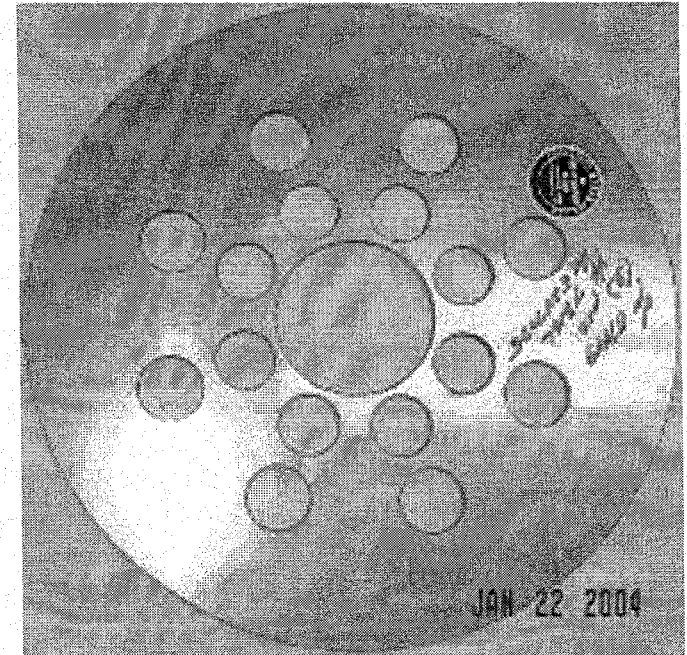
# Imagine...

- Imagine a simple technology that
  - Has no moving parts
  - Is almost indestructible
  - Provides a comparably priced, drop-in replacement for millions of existing devices with similar function
  - Improves system accuracy, repeatability, capability and efficiency
  - **Results in a 3-year life-cycle cost savings of \$5.4 million for an investment of less than \$5K (actual chemical company installation of 2 BFMs)**

# What is Balanced Flow Technology?

- A thin, multi-hole orifice plate with holes sized and placed per a unique set of equations
- Produces mass flow, volumetric flow, kinetic energy, or momentum **BALANCE** across the face of the plate
- Flow is proportional to the square root of upstream to downstream differential pressure
- Multiple holes lead to smoother pressure measurement
- Measures and conditions or can limit fluid flow

Chevron-Texaco 18  
inch Commercial  
Plate



# Balanced Flow Technology Potential

- Eliminates or reduces catastrophic failure modes (vs. Turbine flow meters) for human spaceflight while improving performance
- Increases satellite payload capability
- Reduces child and adult drowning deaths while in pools, spas, hot tubs, and jetted tubs
- Provide significant National and International benefits by globally fielding a NASA developed technology  
(Major oil company selected the BFM as their global standard orifice plate)

# The Problems

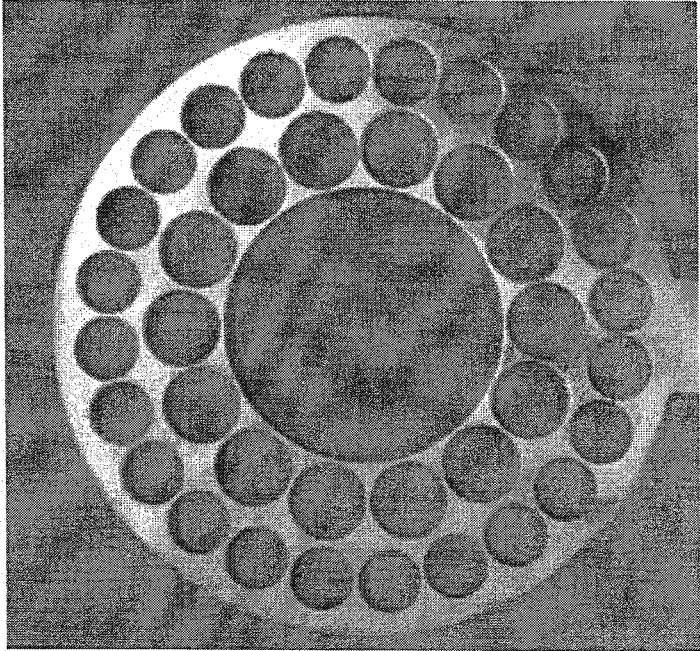
- Inaccurate industrial flow measurements significantly contribute to manufacturing processes operating at 3% or worse accuracy
  - Typical industrial plant employs hundreds of standard orifice plate flow meters
  - Greatly reduces profits
  - Increases pollution emissions leading to fines
  - Consumes unnecessary energy
  - Also need to reduce noise generation to meet EPA regulations
- Rocket engines are inherently dangerous and performance demands constantly increase--want more payload, margin, change mission, etc.
  - Safe LOX flow measurement is difficult (currently use synthetic flow calculation)
  - Accurate flow measurement in rocket environments is difficult
  - Many others...
  - Improper flow measurement or flow device failure can be catastrophic resulting in loss of crew, mission, facilities, or life (single LOX failure resulted in ~\$100 Million in costs)

# Problems Cont.

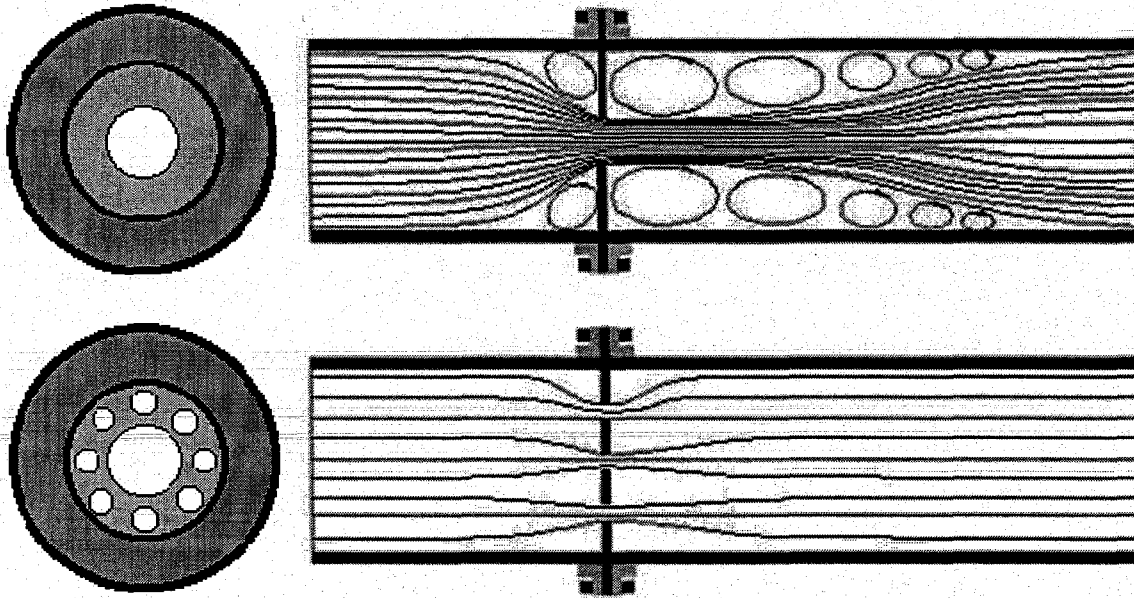
- US Consumer Product Safety Commission estimates 147 cases and 35 deaths directly attributed to pool, spa, hot tub, or jetted tub suction side entrapment (many more may be improperly reported as simple drowning)
  - Pools, spas, hot tubs, and jetted tubs can be safer
  - Implement safety systems to prevent drain suction entrapment

There are many other flow measurement issues in multiple industries

# Balanced Flow Meter Attributes

- Allows measurements where limited options were possible before (Ex. SSME, RS-84 LOX, Target J2X LOX) leading to reduced critical failure modes
  - Provides flow measurement, flow conditioning, or controlled flow restriction
  - Ability to condition or measure flow while improving velocity, momentum, energy or other profiles
  - Able to safely survive and function during all engine transients, start-up, shut-down, and restart
  - Functions with minimal straight pipe run
  - Typical accuracy better than 0.5%
- 
- 7.5" NDP Sized for RP1 rocket engine study
  - 81% open area (97% open area possible)
  - **NASA TRL 6 as of 1/30/2007**

# How Does It Work & Perform?



Comparison of standard orifice to balanced flow meter, both with 27.1% open area

Results based on compressed gas testing

- Up to 10X better accuracy (2X in liquid)
- 2X faster pressure recovery (shorter distance)
- 15X noise reduction
- 2.5X less permanent pressure loss
- Exclusively licensed through NASA by A+FlowTek for commercialization

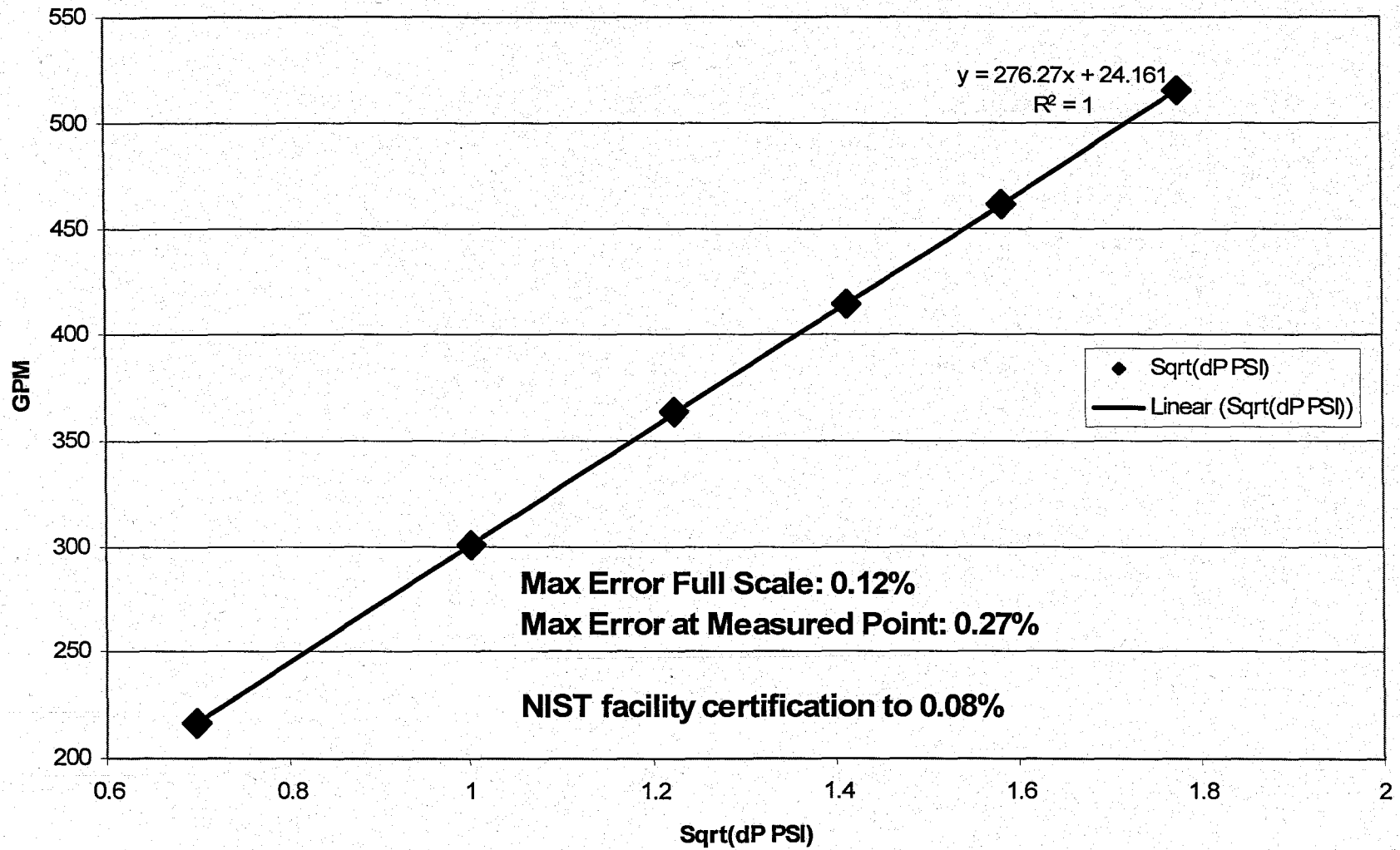


# BFM Utilization and Potential

- Major chemical company stated that by installing 2 high-accuracy BFM plates resulted in \$1.8 million savings per year based solely on pump power required (not including process efficiency gain nor pollution emission savings)
  - 3 year typical life cycle
  - \$5.4 million typical life cycle savings!
- NAVY successfully replaced a non-functional Coriolis meter, operating in a harsh gas environment, with a balanced flow meter without requiring any pipe recertification
  - Purchased second BFM
  - More to come...
- ATK/XCOR successfully fielded BFMs in LOX, liquid methane, and gaseous methane
- NASA In-Space Mixture Ratio Control study determined that application of the BFM to satellite propulsion system may substantially increase payload mass (study and testing continues)
- Etc...

# Calibration Data

Balanced Flow Meter GPM vs Sqrt(dP PSI) for 4-inch Pipe in MSFC 5K Gallon  
H2O Primary Standard Calibration Facility 8-2006



# Configurations Tested



Figure 1 Slotted Configuration

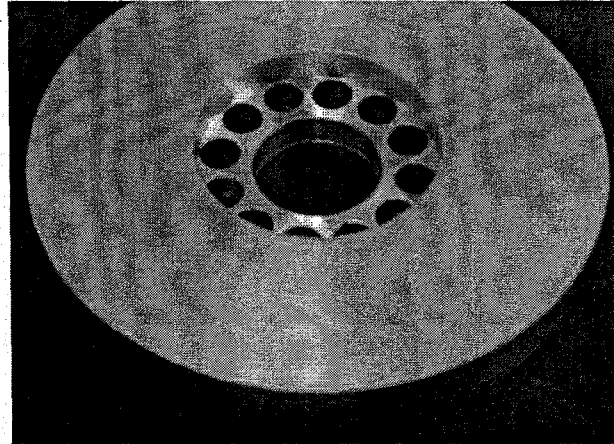


Figure 3 Single Ring of Holes Configuration

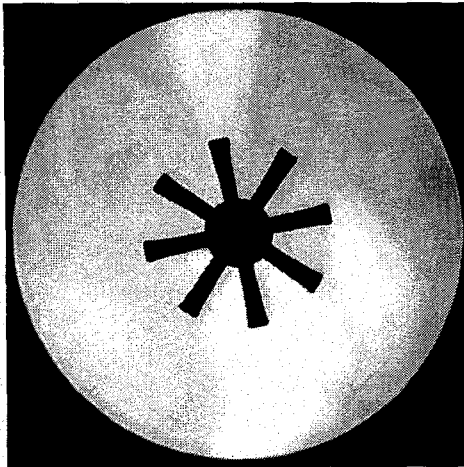


Figure 2 Iron Cross Configuration

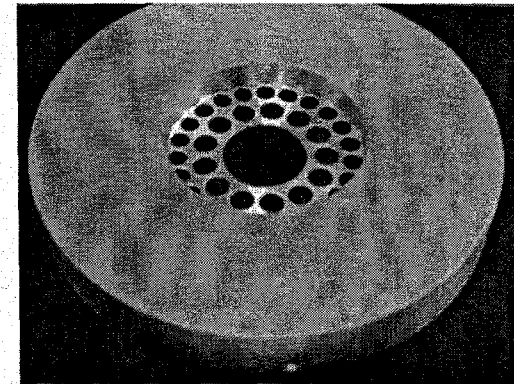


Figure 4 Custom Hole Configuration

**Comparable to a Venturi meter in permanent pressure loss, accuracy and discharge coefficient without the Venturi pipe length and weight!**

# ATK/XCOR LOX/Methane Engine Tests



# Why is BFM deserving of international recognition as NASA's Invention of the year?

## **Meets NASA's National and International public relations goals**

- Is a NASA developed, commercially licensed product sold globally (US, Venezuela, Chili, Saudi to date...China soon)
- Decreases energy consumption by reducing pump energy requirements
- Reduces pollution
- Expanding National & International user base (Chinese company projects 1000, 2000, and 3000 sales per year through 2009)
- Applies to other US government organizations (NAVY, NRO, Air Force, etc.)
- Applies to and benefits a broad range of National and global industries including textiles, chemical, petroleum, oil natural gas, paper, waste, water, etc. (flow meters are everywhere)

# Is Innovation significance sufficient to win either the Commercial or Government Invention of the year?

- YES
- Applies to a broad range of National and International industries including textiles, chemical, petroleum, oil, natural gas, etc. and will save money, improve process efficiency, and reduce pollution that benefits the World
- Commercial applications growing quickly
  - New sales increasing Nationally and Internationally
  - Repeat sales increasing
  - Types of meters replaced increasing (Venturi, Vortex, Coriolis, Orifice, etc.)
- Applicable to a broad range of government entities including NASA, NAVY, NRO, Air Force, etc.
  - NASA XCOR LOX/Methane rocket engine
  - Successfully utilized on a NAVY ship to date...more to come
  - NASA In-Space Mixture Ratio Control study determined that application of the BFM to satellite propulsion system may substantially increase payload mass (study and testing continues)
  - Reduces or eliminates rocket engine critical failure modes while improving efficiency
  - Efforts have improved MSFC water flow calibration capabilities from 0.3% to 0.08%, which will benefit future MSFC flow meter calibrations
- Information generated by the BFM is making pools, spas, and jetted bathtubs safer resulting in fewer drowning deaths



# Questions?

- Q1: Assume Exxon global results in 10,000 meters per year, how much would NASA get?
  - $10,000 \times \$5,000$  (large pipe estimated average gross sale)  $\times 0.06\%$  (contract royalty to NASA) = \$3,000,000
  - More conservative estimate  $1000 \times \$2000 \times 6\% = \$120,000$
  - In North America, there are 41,364 industrial facilities and 252 major refineries each with hundreds of flow meters requiring maintenance turnarounds
- Q2: Have we looked at putting these meters into utilities such as water, natural gas and steam service?
  - Yes, talking with MSFC facilities about evaluating BFM performance verses some of their other meter types (primarily turbine, orifice, and Venturi)
  - Working to get BFM rated for custody transfer applications, which would mean it could go into oil and gas pipelines
    - Very large market
    - Pipelines typically have one meter per mile of pipe with the meter changed or recalibrated every 3 years